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QUARTERMASTER RESEARCH & ENGINEERING COMMAND
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TECHNICAL REPORT
EP-153

THE EFFECT OF INSULATING THE PALM AND BACK OF HANDS ON FINGER COOLING

QUARTERMASTER RESEARCH & ENGINEERING CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

JUNE 1961

NATICK, MASSACHUSETTS

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AD- Div. 28

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Supplementary findings of the study were that added dorsum insulation reduced the rate of cooling of the dorsum area but did not offset the heat loss from the palm. Conversely, additional palm insulation lessened the rate of cooling of the palm but did not alter the rate of dorsum cooling. Reductions in finger-cooling rate due to the presence of added dorsum insulation did not necessarily follow from reductions in the rate of dorsum cooling.

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Project Reference:
7X83-01-009

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FOREWORD

THE SOLDIERS'S ABILITY TO PERFORM OPERATIONS IN THE COLD WILL BE IMPAIRED UNLESS HIS HANDS ARE GIVEN ADEQUATE THERMAL PROTECTION. PLACING LARGE AMOUNTS OF INSULATION OVER THE ENTIRE HAND HELPS TO PROVIDE SUCH PROTECTION BUT ALSO CAUSES LOSS IN MANUAL DEXTERITY. HENCE, TECHNIQUES FOR HAND INSULATION ARE NEEDED IN WHICH THE ASSOCIATED LOSS IN DEXTERITY IS MINIMIZED. THE BEST COMPROMISE BETWEEN PROTECTION AND DEXTERITY MUST BE SOUGHT. THE PRESENT INVESTIGATION EVALUATES ONE POSSIBLE METHOD FOR RESOLVING THIS PROBLEM.

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CONTENTS

ABSTRACT

THE EFFECT OF ADDED INSULATION OF THE DORSUM (BACK) OR PALM OF THE HAND, OR BOTH, ON THE RATE OF FINGER COOLING WAS STUDIED. ADDITIONAL INSULATION ON THE DORSUM WAS FOUND TO REDUCE THE RATE OF FINGER COOLING AT -20°F BUT NOT AT 0°F HAND-COOLING TEMPERATURES. ADDED PALM INSULATION HAD NO EFFECT ON FINGER COOLING UNDER EITHER OF THESE TWO COLD-EXPOSURE CONDITIONS. COMBINED DORSUM AND PALM INSULATION PRODUCED A REDUCTION IN THE RATE OF FINGER COOLING AT -20°F; THIS WAS LARGELY ATTRIBUTABLE TO THE DORSUM INSULATION ALONE. WITHIN THE RANGE OF INSULATION VALUES USED, SYSTEMATIC INCREASES IN THE AMOUNT OF DORSUM INSULATION WERE NOT FOUND TO CAUSE SIGNIFICANTLY GREATER REDUCTIONS IN THE RATE OF FINGER COOLING.

SUPPLEMENTARY FINDINGS OF THE STUDY WERE THAT ADDED DORSUM INSULATION REDUCED THE RATE OF COOLING OF THE DORSUM AREA BUT DID NOT OFFSET THE HEAT LOSS FROM THE PALM. CONVERSELY, ADDITIONAL PALM INSULATION LESSENED THE RATE OF COOLING OF THE PALM BUT DID NOT ALTER THE RATE OF DORSUM COOLING. REDUCTIONS IN FINGER-COOLING RATE DUE TO THE PRESENCE OF ADDED DORSUM INSULATION DID NOT NECESSARILY FOLLOW FROM REDUCTIONS IN THE RATE OF DORSUM COOLING.

THE EFFECT OF INSULATING THE PALM AND BACK OF HANDS ON FINGER COOLING

INTRODUCTION

IN HANDWEAR DESIGN, ONE OF THE SIMPLER WAYS TO IMPROVE THERMAL PROTECTION IS TO INCREASE INSULATION ALL OVER THE HANDS. HOWEVER, THIS INVOLVES LOSSES IN MANUAL PROFICIENCY, ESPECIALLY FOR TASKS DEMANDING SKILLFUL MANIPULATION AND FINE TACTILE DISCRIMINATION. IN RECOGNITION OF THIS PROBLEM, VARIOUS PROPOSALS HAVE BEEN MADE FOR IMPROVING HAND INSULATION WHILE AT THE SAME TIME MINIMIZING THE IMPAIRMENT ASPECTS OF SUCH PROTECTION. FOR EXAMPLE, INSTEAD OF APPLYING LARGE AMOUNTS OF INSULATION OVER THE ENTIRE HAND, INSULATION MIGHT BE GRADED ACCORDING TO THE RATE OF COOLING OF DIFFERENT HAND AREAS (1). THAT IS, GREATER AMOUNTS OF INSULATION WOULD BE PLACED OVER THOSE PARTS WHICH COOL FAST, AND PROPORTIONATELY LESSER AMOUNTS OVER THOSE PARTS WHICH COOL MORE SLOWLY UNDERLYING THIS TECHNIQUE IS THE NOTION THAT ELIMINATION OF NEEDLESS INSULATION IN CERTAIN HAND AREAS SHOULD PERMIT GREATER MOBILITY. HOWEVER, SINCE THE FINGERS COOL MORE RAPIDLY THAN OTHER PARTS OF THE HAND (1, 3), THE OBVIOUS WEAKNESS IN THIS APPROACH IS THAT THE GREATEST AMOUNT OF INSULATION IS PLACED JUST WHERE IT DOES THE MOST DAMAGE TO DEXTERITY AND TACTILE SENSITIVITY.

AS AN ALTERNATIVE, IT HAS BEEN SUGGESTED THAT THE HANDS BE STRIPPED OF ALL INSULATION; THAT THE HEAT SUPPLY TO THE HANDS BE INDIRECTLY DERIVED THROUGH WARMING OTHER BODY AREAS (5). IN FACT, A STUDY ALONG THESE LINES SHOWED THAT HEATING THE FOREARMS LESSENED THE DECREMENT IN MANUAL DEXTERITY DUE TO COLD EXPOSURE AND REDUCED THE RATE OF COOLING OF THE FINGERS (5). HOWEVER, THE AMOUNT OF HEAT NEEDED TO OBTAIN THESE EFFECTS CAUSED DISCOMFORT AND THE MAGNITUDE OF THE EFFECT WAS CONSIDERED TOO SMALL TO BE OF PRACTICAL SIGNIFICANCE.

OF PRIMARY CONCERN IN THIS REPORT IS STILL ANOTHER METHOD FOR REDUCING THE ENCUMBRANCES ASSOCIATED WITH PROTECTIVE HAND INSULATION. IN THIS PROCEDURE, MINIMAL INSULATION WOULD BE GIVEN TO THE FINGERS AND MAXIMAL INSULATION TO THOSE HAND AREAS (BACK AND PALM) WHERE IT WOULD LEAST INTERFERE WITH MANUAL PERFORMANCE. THE USEFULNESS OF THIS APPROACH DEPENDS UPON DEMONSTRATING THAT HEAT RETENTION IN THE FINGERS CAN BE FACILITATED BY INCREASING INSULATION ELSEWHERE ON THE HAND. ALTHOUGH THERE ARE SOME DATA (1) TO SUPPORT THIS NOTION, MORE INFORMATION IS NEEDED FOR AN ADEQUATE APPRAISAL. THEREFORE, THE PRESENT STUDY WAS CONDUCTED TO INVESTIGATE FINGER COOLING AS AFFECTED BY THE AMOUNT OF INSULATION PLACED ON THE DORSUM, OR PALM, OR BOTH OF THESE HAND AREAS. IT WAS ASSUMED THAT ADDED INSULATION ON THESE SURFACES WOULD PRODUCE MINIMAL INTERFERENCE WITH MANUAL PERFORMANCE. FAVORABLE RESULTS WOULD JUSTIFY A COMPREHENSIVE INVESTIGATION OF THE MANUAL PERFORMANCE CAPABILITIES OF HANDWEAR DESIGNS USING THIS INSULATION PRINCIPLE.

STUDY I

1. METHOD

FIRST, A STUDY WAS CONDUCTED TO DETERMINE IF ADDED INSULATION ON THE DORSUM OR PALM OR BOTH OF THESE HAND AREAS WOULD REDUCE THE RATE OF FINGER COOLING. EIGHT WHITE ENLISTED MEN SERVED AS SUBJECTS AND WERE INDIVIDUALLY TESTED 1 1/4 HOURS A DAY FOR 12 DAYS. WITH THE EXCEPTION OF BLACK COFFEE, NO FOOD WAS CONSUMED FOR AT LEAST 12 HOURS BEFORE THE EXPERIMENTAL SESSIONS. THE MEN WERE DRESSED IN SHORTS AND SHOES DURING EACH TEST SESSION AND WERE EXPOSED TO AN AMBIENT TEMPERATURE OF 75°F AND A RELATIVE HUMIDITY OF 50%. HAND SKIN TEMPERATURE MEASUREMENTS WERE TAKEN UNDER 12 DIFFERENT EXPERIMENTAL CONDITIONS REPRESENTING ALL COMBINATIONS OF 3 HAND-COOLING TEMPERATURES AND 4 INSULATION CONDITIONS. THE 3 HAND-COOLING TEMPERATURES WERE 20°F, 0°F, AND -20°F, AS OBTAINED IN A COOLING BOX EQUIPPED WITH PORTS FOR INSERTION OF THE HANDS. THE FOUR INSULATION CONDITIONS CONSISTED OF BOTH HANDS BEING COVERED WITH:

A. 5-FINGER WOOLEN INSERTS* ONLY
B. 5-FINGER WOOLEN INSERTS WITH DORSAL INSULATION PADS
C. 5-FINGER WOOLEN INSERTS WITH PALMAR INSULATION PADS
D. 5-FINGER WOOLEN INSERTS WITH BOTH DORSAL AND PALMAR INSULATION PADS

THE INSULATION PADS CONSISTED OF A MOHAIR FRIEZE CLOTH FILLER (DOUBLE FACE, 15 TO 18 OZ.) COVERED BY NYLON TAFFETA (3 OZ.). THE LENGTH AND WIDTH OF THE PADS CONFORMED TO THE DIMENSIONS OF THE RIGHT AND LEFT HANDS FOR LARGE, MEDIUM, AND SMALL HANDSIZE, AS SPECIFIED FOR THE 5-FINGER WOOLEN INSERT. EACH PAD WAS 1/2 INCH IN THICKNESS AND HAD AN ESTIMATED INSULATION VALUE OF 1.5 CLO.

SEWN ON EACH PAD WERE 5 RINGLETS OF 1/4-INCH ELASTIC RIBBON THROUGH WHICH THE FINGERS WERE PASSED TO HOLD THE PAD ON THE HAND. THE GLOVES WERE WORN OVER THE PADS; THIS ALSO HELPED TO KEEP THE PADS IN PLACE.

2. PROCEDURE

AT THE BEGINNING OF EACH TEST SESSION, COPPER-CONSTANTAN THERMOCOUPLES WERE TAPED TO THE BACKS OF THE 3RD, 4TH, AND 5TH FINGER TIPS AND TO THE CENTER OF THE DORSUM AND PALM OF EACH HAND. APPROPRIATELY-SIZED GLOVES AND INSULATION PADS (IF REQUIRED FOR THE SPECIFIC TEST SESSION) WERE THEN FITTED ON THE SUBJECT'S HANDS AND SKIN TEMPERATURE READINGS TAKEN FOR 5 MINUTES ON A LEEDS AND NORTHRUP MULTIPOINT RECORDER (MODEL G). AT A SIGNAL FROM THE EXPERIMENTER, THE SUBJECT PASSED HIS HANDS INTO THE COOLING BOX AND PLACED THEM IN TWO U-SHAPED SLOTS (SEE FIG. 1). THERMOCOUPLE

*"INSERT" AND "GLOVE" WILL BE USED INTERCHANGEABLY IN THIS REPORT.

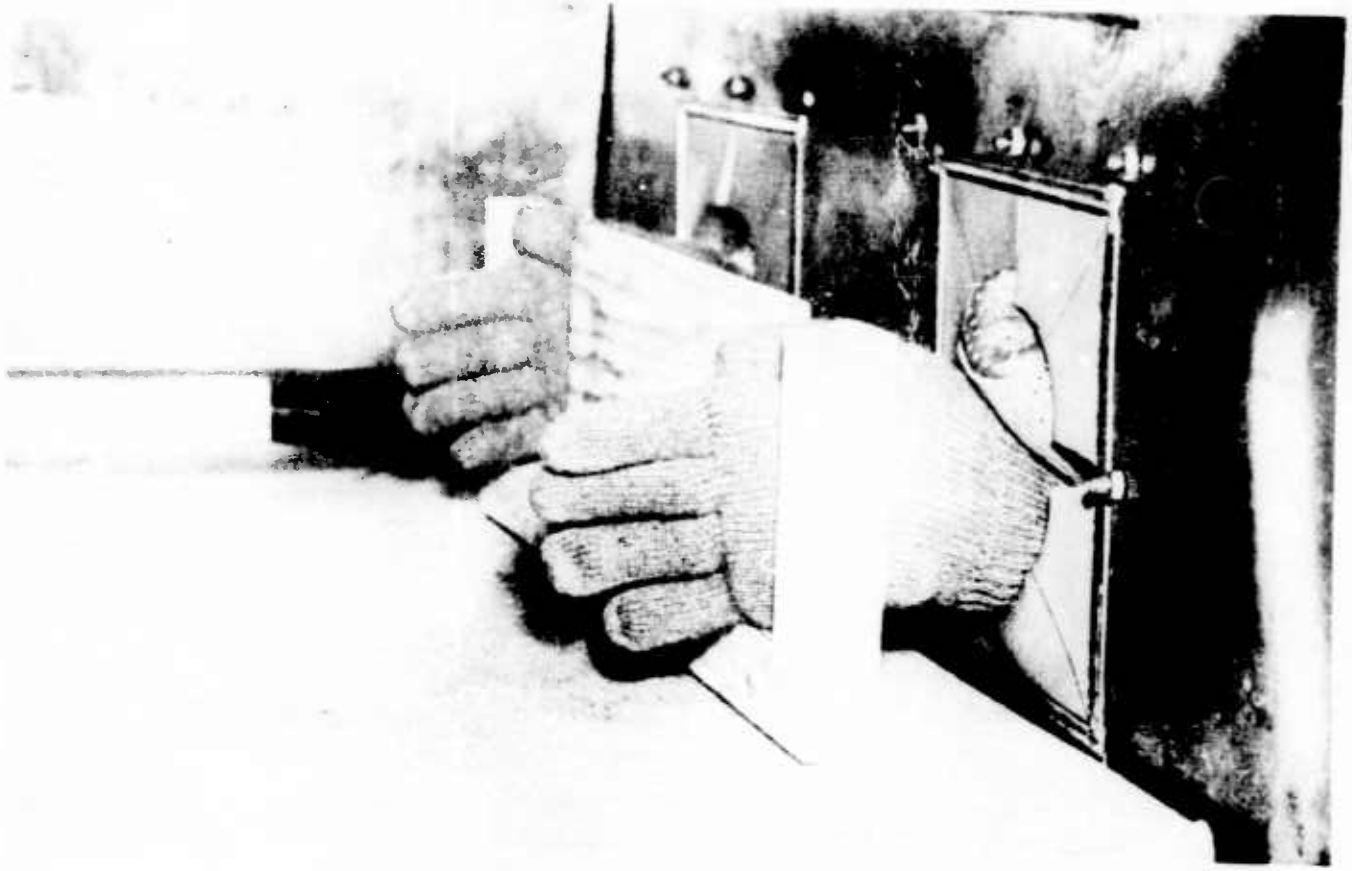

FIGURE 1. POSITION OF SUBJECT'S HANDS IN HAND-COOLING BOX.

READINGS OF THE FINGERS AND HAND SURFACES WERE MONITORED CONTINUOUSLY UNTIL THE FINGER TEMPERATURES OF BOTH HANDS AVERAGED 45°F. WHEN THEY REACHED THIS VALUE, THE SUBJECT TOOK HIS HANDS OUT OF THE COOLING BOX.

THE TIME REQUIRED FOR THE AVERAGE OF THE FINGER READINGS TO DROP FROM THE PRE-COOLING VALUE TO 45°F WAS NOTED ON A STOPWATCH. DIVIDING THIS TIME INTO THE TEMPERATURE LOSS OF THE FINGERS, THAT IS, THE AVERAGE PRE-COOLING FINGER TEMPERATURE MINUS 45°F, YIELDED THE SUBJECT'S RATE OF FINGER COOLING FOR EACH SET OF EXPERIMENTAL CONDITIONS. THE TEMPERATURE DROP OF THE PALMAR AND DORSAL HAND SURFACES WAS ALSO DIVIDED BY THE COOLING TIME NOTED ABOVE, TO DETERMINE THE RATE OF COOLING FOR EACH OF THESE AREAS.

AS A PRECAUTION AGAINST FROSTBITE, THE HANDS WERE REMOVED FROM THE COOLING BOX WHEN ANY SINGLE FINGER TEMPERATURE READING DROPPED BELOW 40°F. HANDS WHICH DID NOT COOL TO THE PRESCRIBED 45°F TEMPERATURE WITHIN 60 MINUTES WERE ALSO REMOVED FROM THE BOX. IN EITHER OF THE ABOVE-MENTIONED INSTANCES, THE AVERAGE OF THE FINGER TEMPERATURES JUST BEFORE REMOVAL WAS RECORDED AND TAKEN INTO ACCOUNT IN COMPUTING RATES OF FINGER COOLING.

3. Results

TABLE I SHOWS THE MEDIAN* COOLING RATES FOR THE FINGERS, PALM, AND DORSUM FOR THE 4 INSULATION CONDITIONS AT 0°F AND -20°F COLD EXPOSURE. DATA OBTAINED AT 20°F WERE NOT INCLUDED SINCE NO SIGNIFICANT LOSSES IN FINGER SKIN TEMPERATURE, IRRESPECTIVE OF DIFFERENCES IN HAND INSULATION, OCCURRED AT THIS COOLING TEMPERATURE EVEN AFTER A 60-MINUTE EXPOSURE. FIGURES 2A AND 3A SHOW THE MEDIAN TIME FOR FINGERS TO COOL FROM 70°F TO 45°F AT 0°F AND -20°F RESPECTIVELY.** ALSO SHOWN ARE THE ASSOCIATED COOLING CURVES FOR THE DORSUM AND PALM OF THE HAND FOR THESE TWO CONDITIONS OF COLD EXPOSURE.

AS EXPECTED, THE DATA SHOW THAT THE FINGERS COOLED FASTER THAN EITHER THE PALM OR DORSUM UNDER ALL INSULATION CONDITIONS AND THAT ALL AREAS SHOWED A FASTER RATE OF COOLING FOR -20°F. HOWEVER, THE ADDITIONAL INSULATION ON THE PALM, DORSUM, OR BOTH HAND AREAS DECREASED THE HEAT LOSSES FROM THE FINGERS. WHEN COMPARED TO THE INSULATING EFFECT OF THE GLOVES ALONE, THE RESULTS OF ADDING INSULATION TO THE DIFFERENT HAND AREAS MAY BE SUMMARIZED AS FOLLOWS:

*BECAUSE THE DATA WERE BASED UPON A SMALL NUMBER OF SUBJECTS WHO GAVE EXTREMELY VARIABLE SCORES FOR THE DIFFERENT EXPERIMENTAL CONDITIONS, MEDIAN RATHER THAN MEAN VALUES WERE USED TO GIVE A MORE REPRESENTATIVE DESCRIPTION OF THE DATA.

**A STARTING FINGER SKIN TEMPERATURE OF 70°F WAS USED IN PLOTTING THESE CURVES SO AS TO INCLUDE THE DATA OF ALL SUBJECTS, REGARDLESS OF DIFFERENCES IN PRE-COOLING FINGER TEMPERATURES.

At 0°F Hand Cooling Temperature

Adding palm pad reduced finger cooling rate by 2%.
Adding dorsal pad reduced finger cooling rate by 7%.
Adding palm and dorsal pads reduced finger cooling rate by 11%.

At -20°F Hand Cooling Temperature

Adding palm pad reduced finger cooling rate by 11%.
Adding dorsal pad reduced finger cooling rate by 24%.
Adding palm and dorsal pads reduced finger cooling rate by 26%.

A sign test (4) analysis of the differences between the rates of finger cooling noted for the 4 hand-insulation and 2 cold-exposure conditions was performed and is summarized in Table II. None of the differences in finger-cooling rates between the glove and each of the other insulating conditions at 0°F cold exposure were significant. This suggests that the above-noted reductions in the rates of finger cooling at 0°F could be due to chance. Hence, it cannot be established that the added insulation affected finger cooling at 0°F cooling temperature. On the other hand, at -20°F statistically significant differences in rates of finger cooling were found between the glove and glove + dorsal pad conditions, and the glove + dorsal + palmar pad conditions. Such differences could consequently be considered as reliable and indicated that added insulation on the dorsum or on the dorsum and palm effectively retarded the heat loss of the fingers at -20°F. Since insignificant differences were found between glove + dorsal pad and glove + dorsal + palmar pad conditions at -20°F, it is indicated that these two insulation conditions were equally effective in reducing the rate of finger cooling.

TABLE I
MEDIAN COOLING RATES (°F PER MINUTE) OF FINGERS, DORSUM, AND PALM FOR DIFFERENT COOLING AND HAND INSULATION CONDITIONS

Hand Area	Cooling Temp. (°F)	Glove Only	Glove + Dorsal Pad	Glove + Palmar Pad	Glove + Dorsal + Palmar Pads
Fingers	0	1.22	1.13	1.20	1.07
	-20	2.10	1.60	2.01	1.55
Dorsum	0	0.68	0.50	0.72	0.60
	-20	1.24	0.58	1.03	0.69
Palm	0	0.45	0.53	0.34	0.35
	-20	0.79	0.65	0.39	0.42

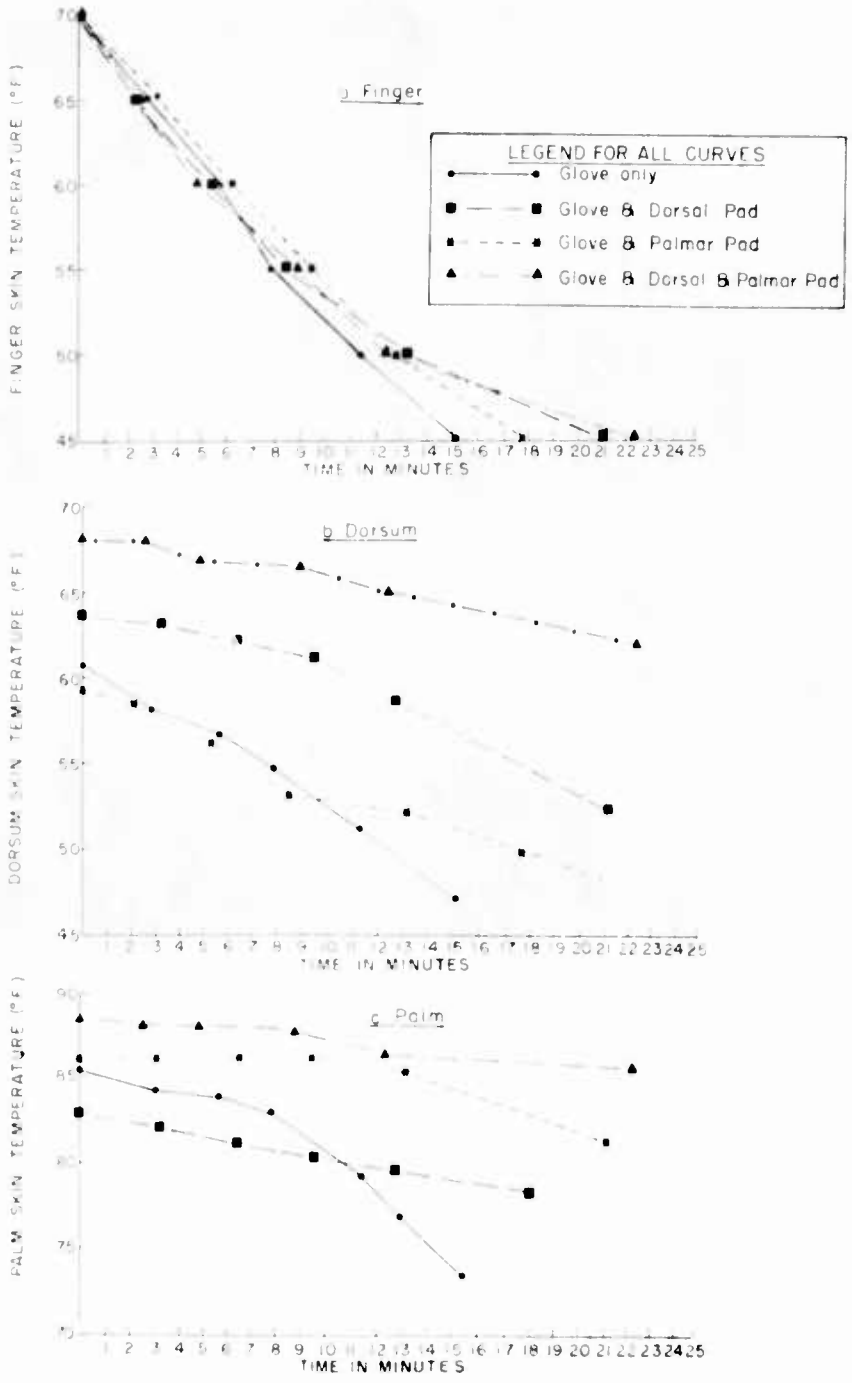

FIGURE 2. MEDIAN COOLING TIME FOR FINGERS, DORSUM, AND PALM AT 0°F UNDER FOUR DIFFERENT HAND-INSULATION CONDITIONS.

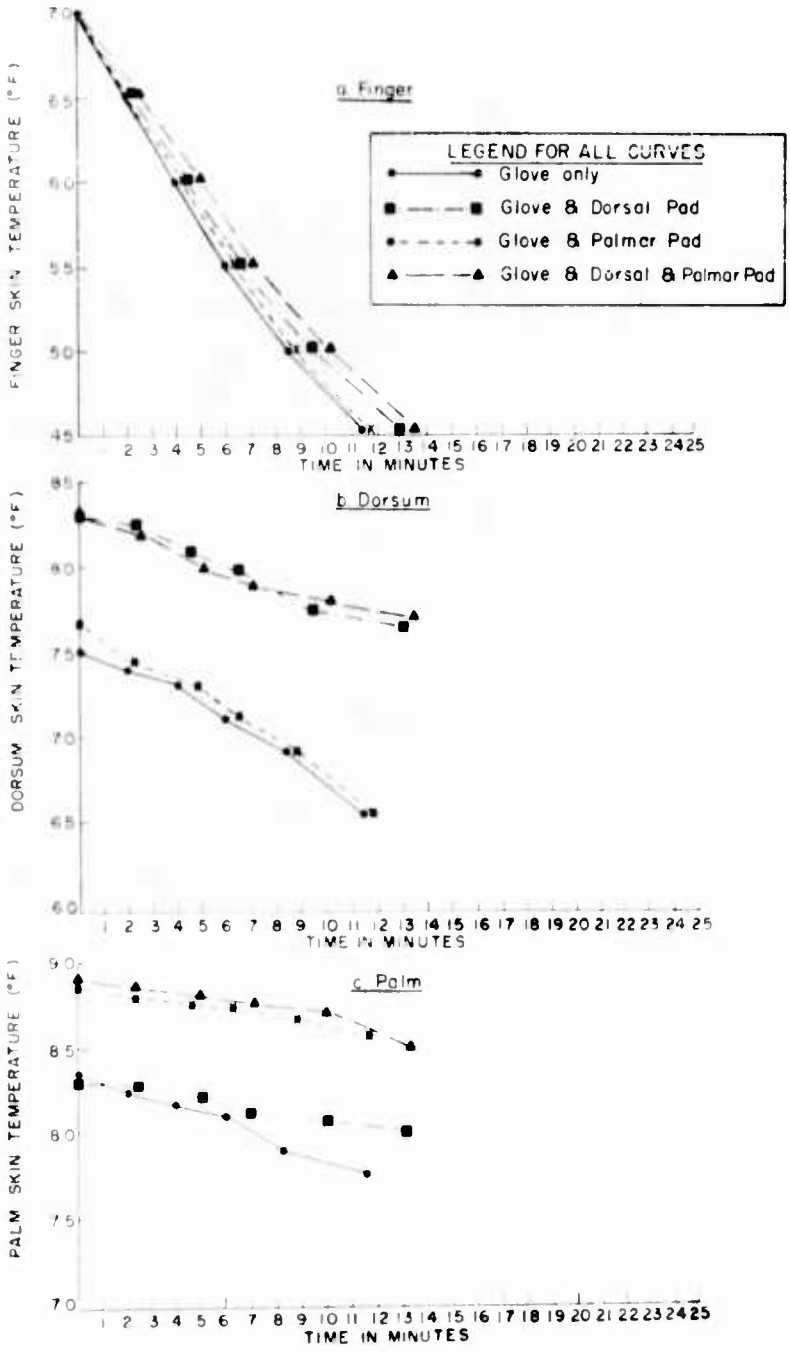

FIGURE 3. MEDIAN COOLING TIME FOR FINGERS, DORSUM, AND PALM AT -20°F UNDER FOUR DIFFERENT HAND-INSULATION CONDITIONS.

TABLE II

DIFFERENCES BETWEEN MEDIAN FINGER COOLING RATES (°F/MIN) FOR DIFFERENT HAND INSULATION AND COOLING CONDITIONS (DIFFERENCE = ROW CONDITION - COLUMN CONDITION)

	0°F Cooling				-20°F Cooling			
Hand Insulation	Glove	Glove + Dorsal Pad	Glove + Palmar Pad	Glove + Dorsal + Palmar Pads	Glove	Glove + Dorsal Pad	Glove + Palmar Pad	Glove + Dorsal + Palmar Pads
Glove	X	.09	.02	.15	X	.50*	.24	.55*
Glove + Dorsal Pad	X	X	.07	-.06	X	X	.26	-.05
Glove + Palmar Pad	X	X	X	.13	X	X	X	.29

*Significant at .05 level.

Although of secondary importance to the present study, differences between rates of palm and dorsum surface cooling for the 4 hand-insulation and 2 cold-exposure conditions were also evaluated by sign tests. As shown in Table III, the results indicate that the palmar and dorsal pads decreased the rate of cooling of their respective areas of placement, the effects being more pronounced at -20°F than at 0°F. Adding insulation to only the palmar surface, however, did not affect the cooling of the dorsum. Conversely, increased dorsum insulation produced no change in the rate of heat loss from the palm. On the other hand, the presence of both pads gave reductions in the rate of cooling of both surfaces which significantly exceeded those noted for the separate palmar and dorsal pad conditions.

4. Discussion

There is evidence in Study I which suggests that the rate of finger cooling may be reduced by applying increased insulation on the dorsal area of the hands. Added insulation on both palm and dorsum also retarded the rate of heat loss from the fingers. The latter effect, however, may be due largely to the dorsal insulation alone, since palmar insulation did not alter finger cooling and the magnitudes of the effects noted under palmar + dorsal insulation conditions were not significantly different from those found under dorsal conditions.

The effectiveness of reducing finger cooling through added dorsal insulation seems dependent upon the cooling temperature and more probably the rate of hand cooling. Given 0°F cold exposure, no significant reduction in finger cooling occurred with added insulation on the dorsal

TABLE III

DIFFERENCES BETWEEN RATES OF DORSAL AND PALMAR SURFACE COOLING (°F/MIN.) FOR DIFFERENT HAND INSULATION AND COOLING CONDITIONS

(DIFFERENCE = ROW CONDITION - COLUMN CONDITION)

HAND INSULATION	DORSUM: 0°F COOLING				DORSUM: -20°F COOLING			
	GLOVE	GLOVE+ DORSAL PAD	GLOVE+ PALMAR PAD	GLOVE+ DORSAL + PALMAR PADS	GLOVE	GLOVE+ DORSAL PAD	GLOVE+ PALMAR PAD	GLOVE + DORSAL + PALMAR PADS
GLOVE	X	.18*	.04	.08	X	.66**	.21	.55**
GLOVE + DORSAL PAD	X	X	-.22*	-.10	X	X	-.45**	-.11
GLOVE + PALMAR PAD	X	X	X	.12	X	X	X	.34*
	PALM: 0°F COOLING				PALM: -20°F COOLING			
GLOVE	X	-.08	.11	.10	X	.14	.40*	.37*
GLOVE + DORSAL PAD	X	X	.19	.18	X	X	.26*	.23*
GLOVE + PALMAR PAD	X	X	X	.01	X	X	X	-.03

*SIGNIFICANT AT THE .05 LEVEL.
**SIGNIFICANT AT THE .01 LEVEL.

SURFACE OF THE HANDS. FOR -20°F COOLING, AND CONSEQUENTLY WITH A FASTER RATE OF HAND COOLING, THE DORSAL INSULATION PRODUCED A SIGNIFICANT DECREASE IN THE RATE OF HEAT LOSS FROM THE FINGERS.

THE RELATIONSHIP BETWEEN REDUCTIONS IN DORSAL AND PALMAR SURFACE COOLING AND REDUCTIONS IN FINGER COOLING FOR COMPARABLE CONDITIONS OF INSULATION DESERVES COMMENT. REDUCTIONS OF THE FINGER COOLING RATE DUE TO DORSAL INSULATION WERE ALWAYS ACCOMPANIED BY SIGNIFICANT REDUCTIONS IN THE RATE OF COOLING OF THE DORSUM. REDUCING THE DORSUM COOLING RATE, HOWEVER, WAS NOT SUFFICIENT TO INSURE A REDUCTION IN FINGER COOLING RATE. FINGER COOLING DID NOT APPEAR TO BE AFFECTED BY RETARDING THE HEAT LOSS OF THE PALM THROUGH THE USE OF THE PALMAR INSULATION PAD. USING BOTH PALMAR AND DORSAL INSULATION PADS CAUSED GREATER REDUCTIONS IN THE RATE OF COOLING OF THE PALM AND DORSUM THAN WHEN USED SEPARATELY. SUCH REDUCTIONS, HOWEVER, WERE NOT ASSOCIATED WITH LARGER REDUCTIONS IN FINGER COOLING RATES.

STUDY II

SINCE THE RESULTS OF STUDY I INDICATED THAT MOST OF THE MAJOR RETARDATION IN COOLING RATES OF THE FINGERS WAS ASSOCIATED WITH DORSAL INSULATION, A SECOND STUDY WAS CONDUCTED TO INVESTIGATE SYSTEMATICALLY THE RELATIONSHIP BETWEEN THE AMOUNT OF DORSAL INSULATION AND FINGER-COOLING RATE.

1. METHOD

EIGHT WHITE ENLISTED MEN SERVED AS SUBJECTS AND WERE INDIVIDUALLY TESTED 1 1/4 HOURS A DAY FOR 6 DAYS. AS IN STUDY I, THE MEN WERE DRESSED IN SHORTS AND SHOES DURING EACH TEST SESSION AND WERE EXPOSED TO 75°F AMBIENT TEMPERATURE AND 50% RELATIVE HUMIDITY. WITH THE EXCEPTION OF BLACK COFFEE, NO FOOD WAS TAKEN FOR 12 HOURS OR MORE BEFORE EACH SESSION. HAND SKIN TEMPERATURE MEASUREMENTS WERE TAKEN UNDER 6 DIFFERENT EXPERIMENTAL COMBINATIONS OF 2 HAND-COOLING AND 3 HAND-INSULATION CONDITIONS. THE 2 HAND-COOLING CONDITIONS WERE 0°F AND -20°F. THE 3 HAND-INSULATION CONDITIONS CONSISTED OF BOTH HANDS BEING COVERED WITH:

A. 5-FINGER WOOLEN INSERTS ONLY
B. 5-FINGER WOOLEN INSERTS WITH DORSAL INSULATION PADS IDENTICAL TO THOSE USED IN STUDY I.
C. 5-FINGER WOOLEN INSERTS WITH DORSAL INSULATION PADS WHICH WERE TWICE THE THICKNESS OF THOSE USED IN STUDY I. THESE PADS HAD AN ESTIMATED INSULATION VALUE OF 2.5 CLO.*

EXCEPT FOR THICKNESS, ALL PADS WERE MADE OF THE SAME MATERIAL AND CAME IN 3 SIZES (LARGE, MEDIUM, AND SMALL) CORRESPONDING TO THE 3 SIZES OF THE 5-FINGER WOOLEN INSERT.

2. PROCEDURE

THE PROCEDURE FOR STUDY II WAS IDENTICAL TO THAT FOLLOWED IN STUDY I.

3. RESULTS

TABLE IV SHOWS THE MEDIAN COOLING RATES FOR THE FINGERS (AS WELL AS THE PALM AND DORSUM) FOR THE 3 HAND-INSULATION AND 2 COLD-EXPOSURE CONDITIONS OF STUDY II. FIGURES 4 AND 5 SHOW THE MEDIAN COOLING TIME FOR THE SKIN TEMPERATURE OF THE FINGERS TO FALL FROM AN AVERAGE OF 70°F TO 45°F FOR THE DIFFERENT INSULATION CONDITIONS UNDER 0°F AND -20°F COOLING. ALSO SHOWN IN THESE FIGURES ARE THE COOLING CURVES FOR THE DORSUM AND THE PALM.

*THE THINNER PAD WILL BE REFERRED TO HEREAFTER AS PAD #1, THE THICKER PAD AS PAD #2.

TABLE IV
MEDIAN COOLING RATES (°F/MIN.) FOR FINGERS, DORSUM, AND PALM FOR DIFFERENT HAND INSULATION AND COOLING CONDITIONS

Hand Area	Cooling Temp. (°F)	Glove	Glove + Pad #1	Glove + Pad #2
Fingers	0	0.70	0.68	0.65
	-20	1.16	0.99	0.80
Dorsum	0	0.58	0.45	0.22
	-20	0.80	0.58	0.54
Palm	0	0.44	0.50	0.33
	-20	0.53	0.51	0.50

In general, the data show that the rate of finger cooling progressively decreased with increasing amounts of dorsal insulation, the reduction being greater for the more severe cooling condition (-20°F). These results can be summarized as follows:

At 0°F Hand-Cooling Temperature

Adding dorsal pad #1 to glove decreased the rate of finger cooling by 3%.
Adding dorsal pad #2 to glove decreased the rate of finger cooling by 7%.

At -20°F Hand-Cooling Temperature

Adding dorsal pad #1 to glove decreased the rate of finger cooling by 15%.
Adding dorsal pad #2 to glove decreased the rate of finger cooling by 31%.

A sign test evaluation of the effects just noted is summarized in Table V. It is shown that only the glove + pad #2 condition at -20°F produced a statistically significant reduction in the rate of finger cooling. The lack of significant differences between glove + pad #1 and glove + pad #2 at -20°F suggests, however, that the glove + pad #1 condition exerted an effect on finger cooling that was comparable to that found for the glove + pad #2 condition.

As in Study I, a sign test evaluation was also performed upon the differences between the rates of cooling for the dorsal and palmar surfaces for different experimental conditions. The results of this analysis are given in Table VI and show that dorsal pad #1 and #2 each significantly lessened the dorsal cooling rate at -20°F. Despite their differences in thickness, however, both pads appeared to produce about the same amount of reduction at this temperature. Only pad #2 significantly altered dorsal cooling at 0°F.

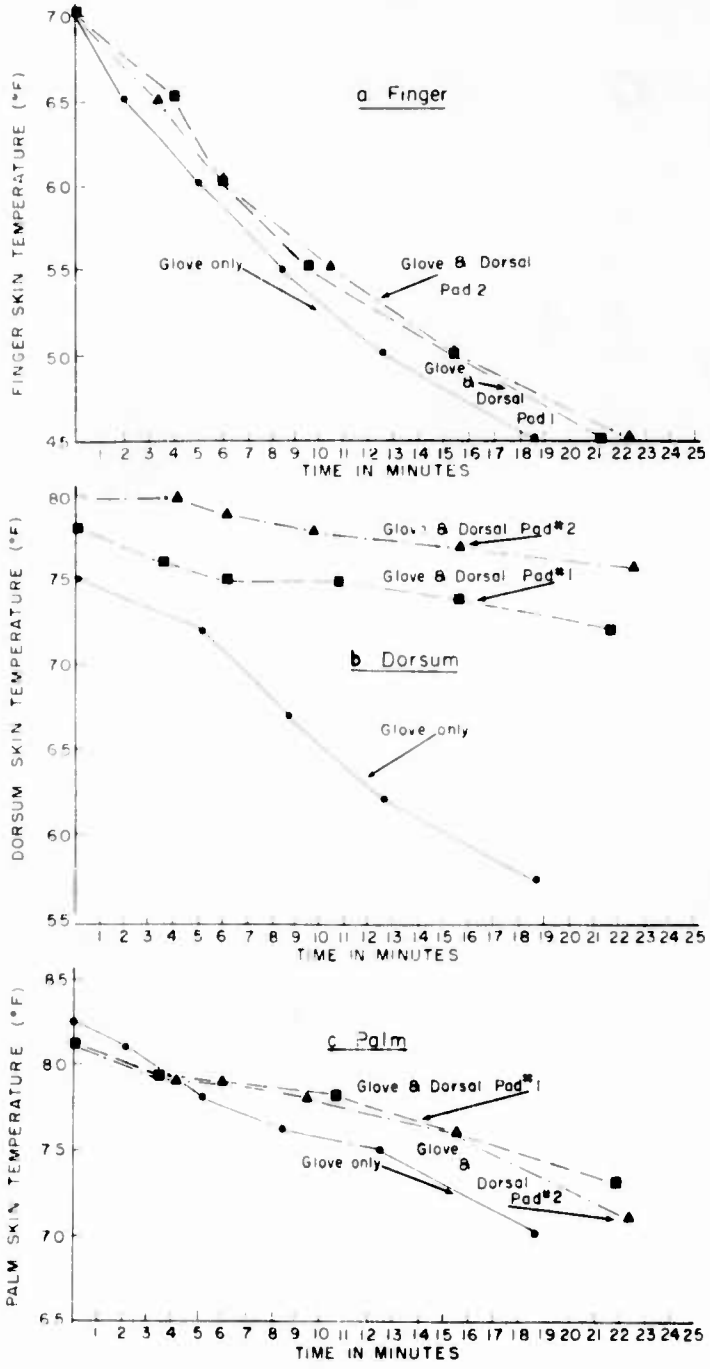

FIGURE 4. MEDIAN COOLING TIME FOR FINGERS, DORSUM, AND PALM AT 0°F UNDER THREE DIFFERENT HAND-INSULATION CONDITIONS.

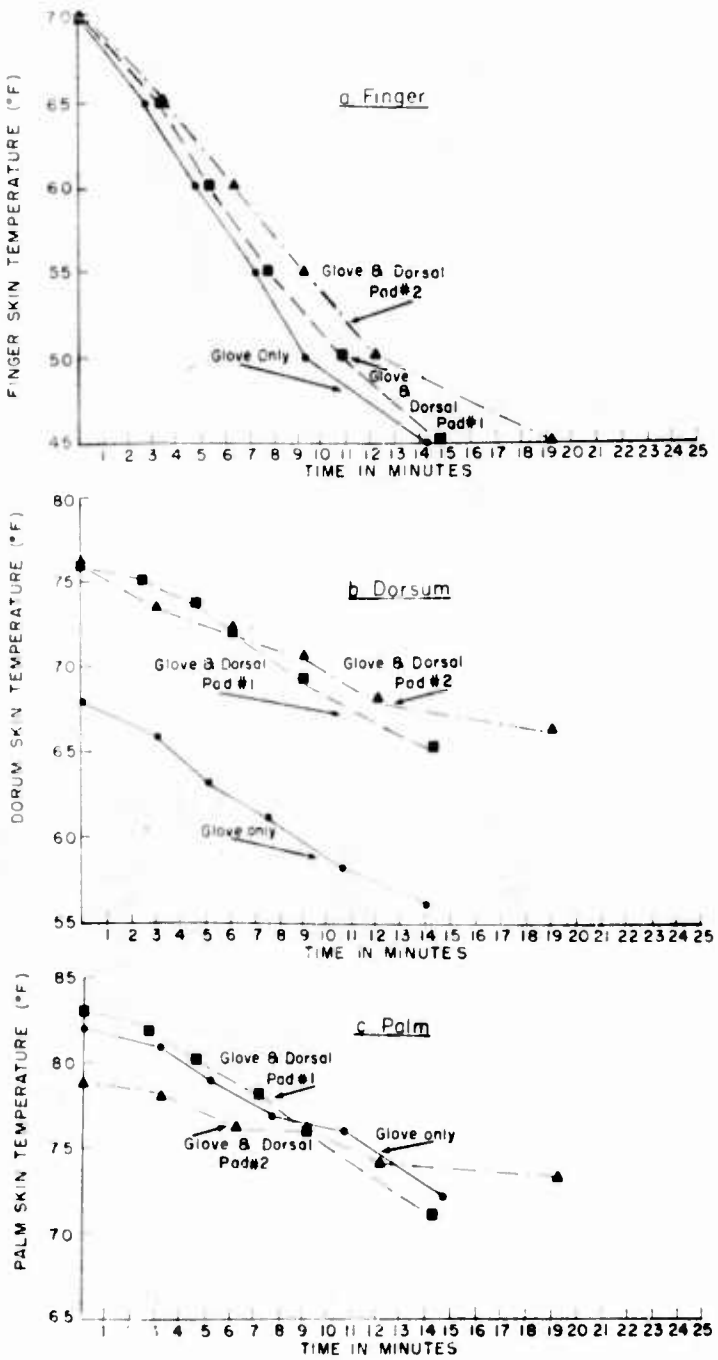

FIGURE 5. MEDIAN COOLING TIME FOR FINGERS, DORSUM, AND PALM AT -20°F FOR THREE DIFFERENT HAND-INSULATION CONDITIONS.

TABLE V

DIFFERENCES BETWEEN MEDIAN FINGER COOLING RATES (°F/MIN.) FOR DIFFERENT HAND INSULATION AND COOLING CONDITIONS (DIFFERENCE = ROW CONDITION - COLUMN CONDITION)

AT 0°F			AT -20°F		
INSULATION	GLOVE + PAD #1	GLOVE + PAD #2	INSULATION	GLOVE + PAD #1	GLOVE + PAD #2
GLOVE	0.02	0.05	GLOVE	0.17	0.36*
GLOVE + PAD #1	X	0.03	GLOVE + PAD #1	X	0.19

*SIGNIFICANT AT THE .05 LEVEL

TABLE VI

DIFFERENCES BETWEEN MEDIAN RATES OF COOLING (°F/MIN.) OF DORSUM AND PALM FOR DIFFERENT HAND INSULATION AND COOLING CONDITIONS (DIFFERENCE = ROW CONDITION - COLUMN CONDITION)

DORSUM: 0°F			DORSUM: -20°F		
INSULATION	GLOVE + PAD #1	GLOVE + PAD #2	INSULATION	GLOVE + PAD #1	GLOVE + PAD #2
GLOVE	0.13	0.36**	GLOVE	0.22*	0.27*
GLOVE + PAD #1	X	0.23*	GLOVE PAD #1	X	0.04
PALM: 0°F			PALM: -20°F		
GLOVE	-0.06	0.11	GLOVE	0.02	0.03
GLOVE + PAD #1	X	0.17	GLOVE + PAD #1	X	0.01

*SIGNIFICANT AT THE .05 LEVEL
**SIGNIFICANT AT THE .01 LEVEL

THE DORSAL PAD, REGARDLESS OF THICKNESS, HAD NO SIGNIFICANT EFFECT UPON PALMAR COOLING AT EITHER 0°F OR -20°F.

4. DISCUSSION

CONSISTENT WITH THE FINDINGS OF STUDY I, THE PRESENT EXPERIMENT SHOWS THAT ADDED DORSAL INSULATION CAUSED A DECREASE IN THE RATE OF FINGER COOLING ONLY UNDER THE MORE SEVERE COOLING CONDITION (-20°F). THE REDUCTION IN FINGER COOLING RATE PRODUCED BY DORSAL PAD #1 IN STUDY II, HOWEVER, WAS NOT AS GREAT AS THAT NOTED FOR COMPARABLE INSULATION AND COOLING CONDITIONS IN STUDY I. THIS RESULT MAY BE EXPLAINED ON THE BASIS THAT THE SUBJECT GROUP IN STUDY I CHARACTERISTICALLY SHOWED A FASTER RATE OF FINGER COOLING THAN THE GROUP USED IN STUDY II. IN FACT, THE MEDIAN RATES OF FINGER COOLING FOR STUDY II SUBJECTS AT -20°F WERE LESS THAN THOSE OBTAINED FOR STUDY I SUBJECTS AT 0°F. ASSUMING THAT THE EFFECTIVENESS OF DORSAL INSULATION VARIES DIRECTLY WITH THE RATE OF FINGER COOLING, IT WOULD BE EXPECTED THAT THE FASTER-COOLING SUBJECTS OF STUDY I WOULD UNDERGO A GREATER REDUCTION IN FINGER COOLING RATE THAN THE SLOWER-COOLING SUBJECTS OF STUDY II.

IT IS DIFFICULT TO DETERMINE FROM STUDY II IF INCREASES IN THE AMOUNT OF DORSAL INSULATION WOULD PRODUCE SYSTEMATICALLY GREATER REDUCTIONS IN THE RATE OF FINGER COOLING. ALTHOUGH PAD #2 PROVIDED A GREATER REDUCTION IN FINGER COOLING THAN PAD #1, THIS DIFFERENCE WAS NOT STATISTICALLY SIGNIFICANT. MOREOVER, THERE IS NO DIRECT EVIDENCE TO INDICATE THAT GREATER REDUCTION IN THE HEAT LOSS OF THE DORSUM WOULD YIELD GREATER REDUCTIONS IN THE RATE OF FINGER COOLING. FOR EXAMPLE, THERE ARE INSTANCES IN BOTH STUDY I AND STUDY II IN WHICH ADDED INSULATION TO THE DORSUM CAUSED SIGNIFICANT LESSENING OF THE DORSUM COOLING RATE BUT HAD NO EFFECT UPON THE RATE OF FINGER COOLING (SEE TABLES II, III, V, AND VI).

NO JUDGMENT CAN BE MADE OF THE MANNER IN WHICH DEXTERITY REQUIREMENTS OR COMBINED COLD AND WIND CONDITIONS MAY ALTER THE MERITS OF DORSAL INSULATION IN REDUCING THE HEAT LOSS FROM THE FINGERS. THIS REQUIRES FURTHER STUDY. THE PRESENT RESULTS DO SUGGEST, HOWEVER, THAT THE DORSAL AREA OF THE HAND SHOULD BE GIVEN IMPORTANT CONSIDERATION FOR THE PLACEMENT OF INSULATION IN FUTURE HANDWEAR SYSTEMS DESIGNED TO PROTECT THE FINGERS AGAINST COLD EXPOSURE.

CONCLUSIONS

THE USE OF ADDED INSULATION ON THE DORSAL SURFACE OF THE HANDS CAUSED A SIGNIFICANT REDUCTION IN THE RATE OF FINGER COOLING. THIS EFFECT, HOWEVER, OCCURRED ONLY UNDER THE MORE SEVERE COOLING CONDITIONS (-20°F) WHERE THERE WAS A FAST RATE OF HAND COOLING. ADDITIONAL INSULATION IN THE PALMAR AREA DID NOT ALTER FINGER COOLING, WHILE COMBINED PALMAR AND DORSAL INSULATION PRODUCED A REDUCTION IN FINGER COOLING WHICH WAS COMPARABLE TO THAT NOTED FOR DORSUM INSULATION ALONE. WITHIN THE RANGE OF

DORSAL INSULATION VALUES USED, SYSTEMATIC INCREASES IN THE AMOUNT OF DORSAL INSULATION DID NOT CAUSE SIGNIFICANTLY GREATER REDUCTIONS IN THE RATE OF FINGER COOLING.

ADDED DORSAL INSULATION REDUCED THE RATE OF COOLING OF THE DORSAL SURFACE BUT DID NOT OFFSET THE HEAT LOSS FROM THE PALM. CONVERSELY, ADDITIONAL PALMAR INSULATION LESSENED THE RATE OF PALMAR COOLING BUT HAD NO EFFECT ON DORSUM COOLING. REDUCTIONS IN THE FINGER-COOLING RATE DUE TO DORSAL INSULATION WERE ALWAYS ACCOMPANIED BY SIGNIFICANT REDUCTIONS IN THE RATE OF COOLING OF THE DORSUM. REDUCING THE DORSUM-COOLING RATE, HOWEVER, WAS NOT SUFFICIENT TO INSURE A REDUCTION IN THE RATE OF FINGER COOLING.

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